DECLARATION

I, Ryuichi YAMADA, a Japanese Patent Attorney registered No. 7898 having my Business Office at Toranomon Sugai Bldg. 2F, 18-16 Toranomon 3-chome, Minato-ku, Tokyo, Japan, solemnly and sincerely declare:

That I have a thorough knowledge of Japanese and English languages; and

That the attached pages contain a correct translation into English of the specification of the following Japanese Application:

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Applicant(s)
CANON KABUSHIKI KAISHA

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<INVENTOR(S)>
<Address> c/o CANON KABUSHIKI KAISHA
30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo
<Name> Kohei NAGAYAMA

<APPLICANT>
<IDENTIFICATION NO.> 000001007
<NAME> CANON KABUSHIKI KAISHA

<ATTORNEY>
<IDENTIFICATION NO.> 100082337
<PATENT ATTORNEY>
<NAME> Kazuo CHIKASHIMA

<DESIGNATED ATTORNEY>
<IDENTIFICATION NO.> 100089510
<PATENT ATTORNEY>
<NAME> Takaharu TAKITA

<OFFICIAL FEES>
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Claims

[Claim 1]

An electrophoretic display device, comprising:

a first substrate;

a second substrate;

a partition wall which is disposed between said first substrate and said second substrate;

a liquid layer which comprises an electrophoretic particle and a dispersion medium disposed in a sealed spacing formed by said first substrate, said second substrate and said partition wall;

a first electrode formed on said first substrate;

a second electrode formed on said partition wall; and

wherein said first electrode and said second electrode are electrically connected with each other through a resistance layer, and a potential gradient is generated in said resistance layer.

[Claim 2]

An electrophoretic display device according to Claim 1, wherein said first electrode is formed at a position most distant from said second electrode.

[Claim 3]

An electrophoretic display device according to

Claim 1 or 2, wherein said resistance layer is integrally formed to cover said second electrode and said first electrode.

[Claim 4]

An electrophoretic display device according to any one of Claims 1 to 3, wherein an electric resistance of said resistance layer is smaller than an electric resistance of said liquid layer.

[Claim 5]

An electrophoretic display device according to Claim 1, wherein an insulating layer is formed between said first electrode and said resistance layer in which said first electrode and said resistance layer are electrically connected with each other through a contact hole.

[Claim 6]

An electrophoretic display device according to Claim 5, wherein said insulating layer comprises the coloring layers.

[Claim 7]

An electrophoretic display device according to Claim 5 or 6, wherein a connection material is filled in said contact hole in which said first electrode and said resistance layer are electrically connected with each other through said connection material.

[Claim 8]

An electrophoretic display device according to

Claim 1, further comprising:

a plurality of data lines which is disposed on a first substrate with a certain pitch;

a plurality of scanning lines and auxiliary capacitance lines which are disposed on said first substrate with a certain pitch while sterically intersecting with said plurality of data lines;

a plurality of pixels which is disposed with a certain pitch, each in correspondence with each of intersections of said data lines and said scanning lines;

said first electrode which is disposed in said pixels;

a plurality of switching devices for ensuring electrical connection between said scanning lines each in correspondence with each of said pixels and a terminal for controlling an Off-state or On-state of said pixels, and for also ensuring electrical connection between said plurality of data lines each in correspondence with each of said pixels and said first electrode of the pixel when the pixel is placed in an On-state;

an auxiliary capacitor to be formed between said first electrode and said auxiliary capacitance line, disposed in said pixel; and

said second electrode disposed in correspondence with said pixel.

[Claim 9]

An electrophoretic display device according to Claim 8, further comprising a plurality of drive voltage lines disposed in said first substrate so as to connect with said first electrodes, respectively; and a means for controlling the electrical current to be flowed to said first electrode between said drive voltage line and said first electrode.

[Claim 10]

A driving method of an electrophoretic display device of the type wherein the device comprises:

a liquid layer, disposed between a first electrode and a second electrode, which comprises the electrophoretic particles and a dispersion medium; wherein a voltage is applied to said first electrode or said second electrode electrically connected through a resistance layer in which an uniform potential gradient is generated in said resistance layer toward said first electrode;

the driving method comprising:

forming a state for collecting said electrophoretic device on said first electrode or said second electrode by moving said electrophoretic device, and an intermediate state therebetween; and

substantially charging a voltage of said first electrode or said second electrode to 0 V.

[Claim 11]

A driving method of an electrophoretic display device of the type wherein the device comprises:

a liquid layer, disposed between a first electrode and a second electrode, which comprises the electrophoretic particles and a dispersion medium; wherein a voltage is applied to said first electrode or said second electrode electrically connected through a resistance layer in which an uniform potential gradient is generated in said resistance layer toward said first electrode, and an insulating layer is formed between said first electrode and said resistance layer, said first electrode and said resistance are electrically connected with each other through a contact hole;

the driving method comprising:

forming a state for collecting said electrophoretic device on said first electrode or said second electrode by moving said electrophoretic device, and an intermediate state therebetween; and

wherein a time until a voltage of said first electrode or said second electrode is substantially changed to 0 V is longer than a time constant determined by the capacitance of said insulating layer and the resistance of said resistance layer after the electrophoretic device is driven.

[Document]

Specification

[Title of the Invention]

Electrophoretic Display Device and Driving Method of Electrophoretic Display Device

[Field]

The present invention relates to an electrophoretic display device and a driving method of the electrophoretic display device.

[Prior Art]

With development of information equipment, the needs for low-power and thin display apparatuses having grown, so that extensive study and development have been made on display apparatuses fitted to these needs.

Such a display apparatus is used frequently outdoors particularly as a wearable PC (personal computer) or an electronic note pad, thus being desirable that it can save power consumption and space. For this reason, e.g., such a product that a display function of a thin display such as a liquid crystal display and means for inputting coordinate data are integrated, and direct input can be effected by pressing a display item on a display surface with a stylus or finger, has been commercialized.

However, most of liquid crystal materials have no memory characteristic, so that it is necessary to

continuously apply a voltage to the liquid crystal during a display period. On the other hand, a liquid crystal material having a memory function cannot readily ensure reliability in the case of assuming its use in various environments such as outdoor environment as in the wearable PC, thus failing to be put into practical use.

In view of these circumstances, as one of thin and light display apparatuses having memory characteristic, an electrophoretic display device has been proposed. This type of electrophoretic display device includes a pair of substrates disposed with a predetermined spacing between pair of substrates, an insulating liquid filled in the spacing of the substrates, a multiplicity of charged electrophoretic (migration) particles dispersed in the insulating liquid, a pair of electrodes disposed closed to the insulating liquid, and an insulating layer disposed to cover the electrodes (e.g., Patent Document 1).

Figures 16(a) and 16(b) show an embodiment of a structure of such a conventional electrophoretic display device, wherein various types of display are effected by utilizing a difference in color between the case of distributing a large number of charged electrophoretic particles 104 disposed in a insulating liquid 103 in a side area as shown in Figure 16(a) and the case of collecting the electrophoretic particles

104 in a narrow area as shown in Figure 16(b). As shown in Figures 16(a) and 16(b), the charged electrophoretic display device includes a pair of substrates 101 and 102, the insulating liquid 103, the electrophoretic particles 104, a pixel electrode 105, a common electrode 106 disposed to partition pixels, and insulating films 107 and 108 which cover the electrodes 105 and 106, respectively.

Patent Document 1: U.S. Patent No. 3,421,494

[Disclosure of the Invention]

[Problems to be Solved]

According to the inventor's analysis, in the conventional electrophoretic display device, an equipotential line is indicated by dotted lines as shown in Figure 17 when a voltage is applied between the pixel electrode 105 and the common electrode 106. As apparent from this figure, the equipotential line is dense at a pixel peripheral portion where a distance between the electrodes 105 and 106 is small, so that an electric field is strong. At a central portion of pixel G, an electric field is weak. In other words, it is found that an electric field (distribution) in a liquid layer comprising the insulating liquid 103 and the charged electrophoretic particles 104 is nonuniform. In such a vertical movement type electrophoretic display device that electrophoretic particles are moved between electrodes

disposed on upper and lower substrates, such a nonuniform electric field is not caused to occur but in the case of a horizontal movement type electrophoretic display device as shown in Figures 16(a) and 16(b), the charged electrophoretic particles are generally moved between an electrode in pixel and an electrode at a pixel peripheral portion, so that a considerable nonuniform electric field is caused to occur.

For this reason, in the case where halftone is displayed, when the charged electrophoretic particles is partially moved on a display electrode depending on an applied voltage, a relationship between the applied voltage and halftone level is largely deviated from a linear relationship, so that it becomes difficult to effect control. As a result, stable gradation cannot be displayed.

Further, in the case of displaying black, by applying a negative-polarity voltage to the pixel electrode 105 to collect the charged electrophoretic particles on the pixel electrode, the black display is effected. However, an electric field toward the central portion of the pixel G is very weak, so that the electrophoretic particles do not reach the pixel central portion, thus failing to provide a sufficient contrast.

In a strong electric field place, the charged

electrophoretic particles and counter ions cause very large polarization, so that when a short circuit is caused between the electrodes after a voltage for moving the charged electrophoretic particles is applied between the electrodes, a depolarization field due to repulsion between particles and attraction force between the particles and the ions is generated to move the electrophoretic particles. As a result, a display memory characteristic is lost in some cases.

On the other hand, in a color electrophoretic display device, a color filter method is most simple. In a conventional color electrophoretic display device, the color filter is formed on an opposite substrate or a reflection electrode.

In the case of forming the color filter on the opposite substrate, a cell is assembled so that the color filter and the pixel are aligned with each other. However, in this case, a positional deviation of the color filter from the pixel is caused to occur. When such a positional deviation is caused to occur, color mixture occurs between adjacent pixels, so that it is necessary to provide the opposite surface with a black matrix by a positional alignment margin in order to prevent the color mixture.

However, in the case of providing the black matrix, it is difficult to obtain a high aperture ratio. Particularly, a lowering in aperture ratio is

noticeable in the case of forming high definition pixels of not more than 150 ppi or using a plastic surface having a high thermal expansion coefficient.

On the other hand, in the case of forming the color filter on the reflection electrode, as shown in Figure 18, it is possible to suppress the lowering in aperture ratio by directly forming color filters 109a, 109b and 109c at a pixel G. In such a cell structure, a residual DC leading to burn-in is caused to occur in some cases, thus impairing a memory characteristic.

As a countermeasure thereagainst, it is possible to use a method wherein on an insulating layer, i.e., a color filter, a transparent electrode is formed to prevent a residual DC of the insulating layer to remain thereat. However, the resultant structure is complicated and in addition, light absorption by the transparent electrode cannot be negligible.

For this reason, by it has been desired that the problems of the conventional electrophoretic display device are remedied to retain the memory characteristic and improve a brightness.

[Means for Solving the Problems]

According to a principal aspect of the present invention, there is provided an electrophoretic display device, comprising: a first substrate; a second substrate; a partition wall which is disposed between the first substrate and the second substrate;

a liquid layer which comprises an electrophoretic particle and a dispersion medium disposed in a sealed spacing formed by the first substrate, the second substrate and the partition wall; a first electrode formed on the first substrate; a second electrode formed on the partition wall; and wherein the first electrode and the second electrode are electrically connected with each other through a resistance layer, and a potential gradient is generated in the resistance layer.

According to another aspect of the present invention, there is provided a driving method of an electrophoretic display device of the type wherein the device comprises: a liquid layer, disposed between a first electrode and a second electrode, which comprises the electrophoretic particles and a dispersion medium; wherein a voltage is applied to the first electrode or the second electrode electrically connected through a resistance layer in which an uniform potential gradient is generated in the resistance layer toward the first electrode; the driving method comprising: forming a state for collecting the electrophoretic device on the first electrode or the second electrode by moving the electrophoretic device, and an intermediate state therebetween; and substantially changing a voltage of the first electrode or the second electrode to 0 V.

[Description of the Preferred Embodiments]

Hereinbelow, embodiments for carrying out the present invention will be described with reference to the drawings.

Figure 1 shows a schematic structural view of an electrophoretic display device according to this embodiment of the present invention. In Figure 1, the electrophoretic display device includes a first substrate 1, a second substrate 2 disposed opposite to the substrate 1, and a pixel G. The second substrate 2 is formed of a light-transmissive material, such as transparent glass or a transparent film. Incidentally, the substrate 1 is not necessarily required to be transparent and rigid and thus may be constituted by a film substrate, a metal substrate, or the like.

On the substrate 1, a display substrate-forming member 8 is formed of a transparent material or a material colored a desired color. Examples of the materials may include: plastics, such as acrylic resin, epoxy resin, silicone resin; and glass. In these materials, it is possible to mix inorganic oxide pigments, such as titanium oxide, zinc oxide, and aluminum oxide, or a dye to provide the material with color or light scattering characteristic.

On the display substrate-forming member 8, a first electrode 5 is formed of, e.g., an ITO (indium tin oxide) film or a metal film such as Al film. The

first electrode 5 has a size which is not more than 30 % of a pixel size and may have any shape. However, in order to sufficiently uniformize an electric field in a liquid layer, the first electrode 5 may preferably have a size of not more than 10 % of the pixel size and a shape similar to the pixel G.

Figure 2 is a plan view showing a constitution of the pixel G in this embodiment of the present invention. In each of the pixels G within a pitch of 50 μm, a square-shaped (5 μm x 5 μm) first electrode 5 is formed in a size of 1 % of the pixel G size. In the case where the pixel G has a rectangular shape, the first electrode 5 may be disposed at several portions discretely as shown in Figure 3(a) or in a line-like shape as shown in Figure 3(b).

Referring again to Figure 1, between the first substrate 1 and the second substrate 2, a partition wall 6 for keeping a spacing therebetween at a predetermined level and partitioning adjacent pixels is formed, in a thickness of ordinarily 5 - 30 μm, of a generally used material, such as a resist material, a thermoplastic material, an ultraviolet curable material, or the like. At a substrate of the partition wall 6, a second electrode 7 may be formed of not only a film of metal, such as Al or Ti but also the ITO film.

Thereafter, a resistance layer 9 is formed to

cover the second electrode 7 and first electrode 5. Here, as a material for the resistance layer 9, it is possible to use a light-transmissive material including: films of organic compounds, such as polysilane, polysiloxane, polyacetylene, composites thereof, copolymers thereof, and the like; inorganic films, such as ITO (indium tin oxide) film; semiconductor films, such as silicon film; and electroconductive resin films obtained by adding an electroconductive filler, such as metal powder or carbon particles in epoxy resin, polypropyrene, or the like. The resistance layer may be prepared as an interfacial member by laminating these films. The resistance layer may desirably have a volume resistivity of 10^6 - 10^{12} ohm.cm and a thickness of 1 - 200 nm.

Incidentally, in this embodiment, in order to simplify the production process of the electrophoretic display apparatus, the resistance layer 9 is formed to cover the second electrode 7 and the first electrode 5. However, the resistance layer 9 may be disposed so as to ensure electrical connection between the second electrode 7 and the first electrode 5 through the resistance layer 9.

On the other hand, in a sealed spacing formed by said first substrate, said second substrate and said partition wall, a liquid layer dispersion medium and

the charged electrophoretic particles 4 dispersed in the dispersion medium are filled, and an electrophoretic dispersion liquid 3 for forming a liquid layer is filled into the sealed spacing. Here, as the liquid layer dispersion medium, it is possible to use water, methanol, ethanol, acetone, hexane, toluene, aromatic hydrocarbon such as benzene having a long-chain alkyl group, and other various oil-like compounds, singly or in mixture of these compounds together with a surfactant or the like.

The electrophoretic particles 4 are organic or inorganic particles having such a property that they are moved in the dispersion medium by electrophoretic migration attributable to a potential difference. Examples thereof may include particles of one or two or more species of pigments including: black pigments, such as aniline black, carbon black, and the like; white pigments, such as titanium dioxide, antimony trioxide; azo pigments; and other colored pigments.

In these pigments, as desired, it is possible to add a charge control agent comprising particles of an electrolyte, a surfactant, a resin, a rubber, oil, etc.; a dispersing agent, such as a titanium-based coupling agent, an aluminum-based coupling agent, a silane-based coupling agent, or the like; a lubricant; a stabilizer; and so on.

In this embodiment, between the first electrode

5 and the second electrode 7, a drive voltage generation apparatus for generating a drive voltage is connected.

Next, an operation of the thus constituted electrophoretic display device will be described. In the following description, the case of positively-charged electrophoretic particles 4 are described as an example but the case of negatively-charged electrophoretic particles 4 can be similarly described in consideration of an opposite direction of movement of the electrophoretic particles.

Figures 4(a) to 4(c) show drive waveform diagrams, wherein a potential of the second electrode 7 is 0 V. Figure 4(a) shows a potential of the first electrode. Figure 4(b) shows a potential of a resistance layer (electroconductive film potential) at a point A indicated in Figure 1, and Figure 4(c) shows an optical response. In Figures 4(a) to 4(c), a period between times t1 and t2 is a reset period, and a period between times t2 and t3 is a writing period.

In the reset period, a reset voltage Vr is applied in order to place the electrophoretic particles uniformly in a predetermined position. At this time, a potential of the resistance layer 9 at the point A shown in Figure 1 is an intermediary potential between the second electrode potential (0 V) and the first electrode potential (Vr).

Thereafter, in the writing period, a writing voltage Vw is applied and similarly the resistance layer potential is also changed. As a result, due to a resistive partial voltage, the resistance layer potential is lower than the first electrode potential (Vw).

After the writing, the applied voltage is lowered to 0 V and the writing period is changed to a display state retention period. In this period, when a normal direction resistance of the resistance layer 9 on the first electrode and a normal direction resistance thereof on the second electrode are made sufficiently smaller than a resistance of the liquid layer between the first and second electrodes, a residual DC does not remain. As a result, an electric field in opposite direction is not generated immediately after the applied voltage is lowered to 0 V, so that a memory characteristic is not impaired.

Incidentally, by electrically connecting the first electrode 5 and the second electrode 7 via the resistance layer 9 as described above, in the case of applying a drive voltage, a potential gradient is generated in the resistance layer, so that the potential of the resistance layer 9 is smaller at a position closer to the second electrode 7 and larger at a position more distant from the second electrode 7, due to the resistive partial voltage. Figure 5 shows

a state of equipotential line in this case. As shown in Figure 5, a spacing between equipotential lines between the first and second electrodes 5 and 7 is considerably larger than that in the case of the conventional electrophoretic display device, so that the electric field in the neighborhood of the partition wall.

Accordingly, an extreme nonuniformity of the electric field in the liquid layer is removed, so that an electric field applied to the electrophoretic particles is also substantially uniform. By uniformizing the electric field, it becomes possible to easily control an amount of movement of the electrophoretic particles by changing a pulse width of an applied voltage pulse. As a result, it is possible to effect stable halftone display.

Further, the first electrode 5 is formed at a central portion of the display pixel G, so that a horizontal electric field directed toward the central portion at the time of displaying black is generated. For this reason, the electrophoretic particles reach the central portion to remarkably improve a contrast. Further, by the electric field uniformization, it is possible to suppress an occurrence of depolarization field due to polarization between particles and ions, so that a sufficient memory characteristic can also be obtained.

Next, a second embodiment of the present invention will be described.

Figure 6 is a schematic sectional view showing a constitution of an electrophoretic display device according to this embodiment of the present invention. In Figure 6, the same reference numerals as in Figure 1 represent the same or corresponding portions as in Figure 1.

In the electrophoretic display device shown in Figure 6, an unevenness portion 13 is formed on a first substrate 1 and a first electrode 12 is formed on an upper surface of the unevenness portion 13. The unevenness portion 13 can be formed by, e.g., applying a photosensitive resin onto the substrate 1 and then performing light exposure and wet development or by such a method that a minute unevenness is provided on a glass plate. As a material for the first electrode 12 formed on the unevenness portion 13, it is possible to use a material, having a high reflectance, such as Al or Ag.

As described above, by forming the first electrode 12 on the unevenness portion 13, it is possible to impart a light diffusion function to the first electrode 12. Further, by controlling a distribution of inclination angle at the unevenness portion 13, it is possible to not only increase a viewing angle but also permit effective reflection of

external light, so that it is possible to effect bright and good display compared with the case of First Embodiment of the present invention. Further, it becomes possible to retain a reflectance without using an ITO electrode to simplify a production process.

On the first electrode 12, coloring layers 10a, 10b and 10c are formed to constitute an insulating layer. These coloring layers 10a, 10b and 10c are constituted by an ultraviolet (UV) curable-type acrylic resin resist in which a red pigment, a green pigment, or a blue pigment is dispersed, respectively. These coloring layers 10a, 10b and 10c generally have a thickness of approximately 0.5 - 4 μm.

At a central portion of a pixel G, a contact hole 11 is formed. A resistance layer 9 is formed to cover a partition wall 6 formed on the coloring layers together with a second electrode 7, the coloring layers 10a, 10b and 10c, and the contact hole 11, whereby the first electrode 12 and the second electrode 7 are electrically connected with each other through the resistance layer 9 formed in the contact hole 11.

Further, in this embodiment, the contact hole 11 is formed at a position most distant from the second electrode 7, i.e., at a substantially central portion of the pixel G, whereby a potential difference between

the central portion of the pixel G and the second electrode 7 becomes largest. As a result, an electric field in a horizontal (in-plane) direction toward the central portion of the pixel G is generated at the time of black display, so that the electrophoretic particles 4 reach the pixel central portion to considerably improve a contrast.

Next, an operation of the thus constituted electrophoretic display device will be described. In the following description, the case of positively-charged electrophoretic particles 4 are described as an example but the case of negatively-charged electrophoretic particles 4 can be similarly described in consideration of an opposite direction of movement of the electrophoretic particles.

Figures 7(a) to 7(c) show drive waveform diagrams, wherein a potential of the second electrode is 0 V.

Figure 7(a) shows a potential of the first electrode, Figure 7(b) shows a potential of a resistance layer (electroconductive film potential) at a point A indicated in Figure 6, and Figure 7(c) shows an optical response. In Figures 7(a) to 7(c), a period between times t1 and t2 is a reset period, and a period between times t2 and t3 is a writing period, and a period between times t3 and t4 is a voltage off transition period.

At the time t1, a reset voltage Vr is applied in order to place the electrophoretic particles uniformly in a predetermined position. Immediately after the application of the reset voltage Br, a potential of the resistance layer 9 at a point A shown in Figure 6 is substantially identical to that of the applied voltage since the potential is divided at a ratio of capacitance between the resistance layer 9 and the first electrode 12 and a capacitance between the coloring layers (insulating layer) 10a, 10b and 10c and the first electrode 12. However, thereafter, the potential is settled at a predetermined voltage by the resistive voltage division of the resistance layer 9. A time constant thereof is adjustable by the resistance of the resistance layer 9 and the capacitance created between the resistance layer 9 and the first electrode.

Thereafter, when the writing voltage Vw is applied in the writing period, the potential of the resistance layer is not less than the voltage Vw by capacitance voltage division but is settled at a predetermined voltage in the resistive voltage division at the same time constant as in the reset period. Then, as shown in Figure 7(c), after the potential is a predetermined gradation level, the operation is performed in the voltage off transition period.

Immediately after the time t3, when the applied voltage is changed to 0 V, an opposite-polarity electric field is generated by electric charges remaining between the resistance layer 9 and the first electrode to impair the memory characteristic. For this reason, when the first electrode potential is gradually changed to 0 V at a time constant longer than the time constant of the cell, it is possible to suppress an occurrence of the opposite-polarity electric field, so that it becomes possible to retain the memory characteristic.

More specifically, the voltage for display is applied between the first electrode 12 and the resistance layer 9 and then is changed to substantially 0 V at a time constant larger than a time constant determined by a capacitance of the coloring layers (insulating layer) 10a, 10b and 10c and the resistance layer 9, whereby it becomes possible to lower the applied voltage to 0 V at a longer time constant than a time constant of the residual DC remaining in the coloring layers (insulating layer) 10a, 10b and 10c. As a result, it is possible to suppress application of the opposite-polarity voltage to the liquid layer, so that a good memory characteristic can be obtained without moving the electrophoretic particles in the opposite direction.

Next, a third embodiment of the present invention will be described.

Figure 8 is a schematic sectional view showing a constitution of an electrophoretic display device according to this embodiment of the present invention. In Figure 8, the same reference numerals as in Figure 6 represent the same or corresponding portions as in Figure 6.

In the electrophoretic display device shown in Figure 8, a connection material 12 is filled in the contact hole 11 in which the first electrode 5 and the resistance layer 9 are electrically connected with each other through the connection material 12. By providing such a constitution, a stepwise portion at the surface of the resistance layer 9 can be reduced, so that it is possible to solve such a problem that the electrophoretic particles 4 are attached to the stepwise portion at the contact hole portion.

Incidentally, as a material for the connection material 12, a material having a low resistance than that of the resistance layer 9 is preferred. It is possible to use metal such as Al or Ti; ITO; electroconductive resin. When the resistance of the connection material is low, it is possible to suppress a potential drop due to the resistance of the connection material 12 at the contact hole portion, so that it is possible to efficiently apply a voltage to

the liquid layer compared with the case of Second Embodiment. As a result, a desired voltage can be applied to the liquid layer. Further, in the case where the connection material 12 is metal, it is possible to sufficiently lower the resistance at the connection portion even when the contact hole 11 has a small size. For this reason, an area of an effective portion for display is increased, so that it is possible to effect bright and good display.

Figure 9 is a block diagram showing a system constitution of an electrophoretic display apparatus using the electrophoretic display device according to any one of First to Third Embodiments, as a display panel. In Figure 9, the electrophoretic display apparatus includes a panel controller 41, a source driver 42, a gate driver 43, and an electrophoretic display panel 44.

The panel controller 41 generates display data and control signals, such as a field synchronizing signal, a horizontal synchronizing signal, and data acquisition clock on the basis of inputted image data, and transfer them to the source driver 43 and the gate driver 42. The source driver 43 and the gate driver 42 output a drive voltage to the electrophoretic display panel 44 in accordance with the control signals and display data received from the panel controller 41. The electrophoretic display panel 44

effects display depending on the drive voltage.

The electrophoretic display panel 44 includes: a plurality of data lines disposed on a substrate with a certain pitch; a plurality of scanning lines and auxiliary capacitance lines which are disposed on the substrate with a certain pitch while sterically intersecting with the plurality of data lines, and a plurality of pixels G disposed with a certain pitch, each in correspondence with each of intersections of the data lines and the scanning lines (not shown).

Figure 10 is an equivalent circuit view at one pixel of the electrophoretic display panel 44 comprising, e.g., the electrophoretic display device (Figure 6) according to Second Embodiment of the present invention. The equivalent circuit includes a pixel 45 having the first electrode 12, which is connected with a drain electrode of a thin film transistor (TFT) 46 as a switching device for active matrix drive display, and the second electrode 7 which is connected with a common electrode 49 having a voltage Vcom. The second electrodes 7 at all the pixels are connected with the common electrode 49. A gate line 47 is connected with a gate electrode of the TFT 46, and a source line 48 is connected with a source electrode of the TFT 46. The TFT 46 is an n-type transistor.

Between the drain electrode of the TFT 46 and an

auxiliary capacitance line 51, an auxiliary capacitor 50 providing a capacitance of the coloring layers is disposed. The auxiliary capacitors at all the pixels are connected with the auxiliary capacitance line 51 which has a voltage Vcs.

Hereinbelow, a specific method will be described.

Figures 11(a) to 11(b) show drive waveforms at certain one pixel of the electrophoretic display panel 44. Here, the potential of the second electrode 7 is 0 V. Figure 11(a) shows a gate signal (scanning signal pulse) inputted from the gate driver 42, Figure 11(b) shows a data (information) signal pulse inputted from the source driver 43 to the first electrode 12, Figure 11(c) shows a first electrode potential waveform and a resistance layer potential waveform, and Figure 11(d) shows an optical response.

Here, a drive period is constituted by three periods of a reset period, a writing period, and a voltage off transition period. In the following description, the case where each period is consisting of two fields will be described but other cases, such as the case where the number of fields in respective periods are different, and the case where each period is consisting of not less than two fields can achieve the effects of the present invention, thus being of no problem.

In the reset period, in synchronism with the

gate signal, a reset pulse Vr1 is applied from the source driver 43 to the source line 48, whereby the voltage Vr1 is written at the pixel (the first electrode 12). During a subsequent field period, the voltage is retained. At this time, the first electrode 12 and the second electrode 7 are electrically connected via the resistance layer 9, so that the first electrode potential is changed at a time constant determined by a resistance of the resistance layer 9 and the auxiliary capacitance 50. An amount of the change in first electrode potential can be decreased by adjusting the resistance of the resistance layer 9 and the auxiliary capacitance 50.

With respect to the resistance layer potential, similarly as in Second Embodiment described above, it is changed to a potential Vr1 by capacitive voltage division and then is settled at a resistive partial voltage of the resistance layer 9. Different from Second Embodiment, in this embodiment, the resistive partial voltage of the resistance layer 9 is also changed depending on the change in first electrode potential.

In a subsequent field in the reset period, the Vr1 is written again in the first electrode 5. At this time, the change in first electrode potential is small, so that a fluctuation in potential of the resistance layer 9 is also small. Thereafter, the

potential is lowered similarly as in the case of the previous field.

When the drive period goes to the writing period, a voltage Vw1 is written in the first electrode 5 and then the voltage is held and a display state is changed from black to white by movement of the electrophoretic particles 4. At this time, the potential of the resistance layer is subjected to potential change in amount substantially equal to a difference in potential between the voltages Vr1 and Vw1, thus being higher than Vw1. Thereafter, the potential is settled at the resistive partial voltage of the resistance layer 9. The potential change in a subsequent field is the same as in the second field in the reset period.

In the subsequent voltage off transition period, a voltage Vs1 is written in a first field and a voltage Vs2 is written in a second field. The resistance layer potential is determined by resistive voltage division of the resistance layer 9, and is changed depending on the first electrode potential.

Here, when the voltage is changed to 0 V immediately after the writing period, the potential of the resistance layer is changed to that of an opposite polarity by electric charges remaining in the coloring layers. As a result, an electric field in an opposite direction is generated to impair the memory

characteristic. In this embodiment, the voltage is lowered while satisfying a relationship: Vw1 > Vs1 > Vs2, whereby a time until the first electrode potential is attenuated to 0 V is longer than a time constant determined by the capacitance of the coloring layers and the resistance of the resistance layer.

On conditions that the coloring layers have a thickness of 1 μm and a dielectric constant of 3 and a pixel size is 50 μm x 50 μm, a capacitance of the coloring layer portion sandwiched between the resistance layer 9 and the first electrode 5 is about 0.13 pF per one pixel except for the contact hole portion. When the resistance layer is formed so that a resistance between the common electrode and the first electrode is 10^{12} ohm, a time constant for removing the residual DC is about 13 ms. In this case, when the first electrode potential is attenuated to 0 V in a time period of 100 ms, the opposite-polarity electric field is not caused to occur. Thus, by providing the time, until the first electrode potential is attenuated to 0 V, longer than the time constant determined by the coloring layer capacitance and the resistance layer resistance, it is possible to lower the first electrode potential and the resistance layer potential to 0 V without generating the opposite-polarity electric field. As a result, the optical response after the writing period is capable

of being not changed. Here, in an actual drive, a display switching speed may preferably be not more than 1 sec. and the attenuation time of the first electrode potential may also preferably be not more than 1 sec. Incidentally, the thickness and dielectric constant of the coloring layers and the resistance layer resistance may be any values so long as the time constant determined by the coloring layers and the resistance layer does not exceed the attenuation time.

According to the above-described driving method, it is possible to improve an electric field nonuniformity in the neighborhood of the partition wall without causing the electric field applied in the opposite direction, so that it becomes possible to considerably improve the memory characteristic, the contrast, and the display qualities of the electrophoretic display panel.

Figure 12 is another equivalent circuit view at one pixel of the electrophoretic display panel 44, wherein a drive power source line 52 and a voltage control TFT 53 are added compared with the case of the equivalent circuit shown in Figure 10. The voltage control TFT 53 is an n-type transistor similarly a the pixel TFT 46.

To a source electrode and a drain electrode of the voltage control TFT 53, the drive power source

line 52 and the first electrode of the pixel 45 are connected, respectively. To the gate electrode, the drain electrode of the pixel TFT 46 is connected.

Hereinbelow, a specific method will be described.

Figures 13(a) to 13(e) show drive waveforms at certain one pixel of the electrophoretic display panel 44. Here, the potential of the second electrode 7 is 0 V. Figure 13(a) shows a gate signal (scanning signal pulse) inputted from the gate driver 42, Figure 13(b) shows a signal line potential (data (information) signal pulse) inputted from the source driver to the pixel, Figure 13(c) shows a Vdd signal, Figure 13(d) shows a first electrode potential waveform and a resistance layer potential waveform, and Figure 13(e) shows an optical response.

In a reset period, in synchronism with the gate signal, a pulse Vt1 is applied from the source driver 43 and written in the gate of the voltage control TFT 53. At this time, the potential of the second electrode 7 is 0 V and the voltage of the drive power source line 52 is -Vdd, so that a potential difference of -Vdd is given between the second electrode and the drive power source line.

Here, on condition that a resistance between the source and the drain of the voltage control TFT53 is controlled by the gate voltage and the resistance under application of the voltage Vt1 is sufficient

smaller than the resistance of the resistance layer between the second electrode and the first electrode, the first electrode potential is substantially -Vdd by resistive voltage division. As a result, it is possible to effect a reset operation of the electrophoretic particles.

In a subsequent field, a voltage Vt0 is written in the gate of the voltage control TFT 53 to place the voltage control TFT 53 in an OFF-state. Here, the OFF state of the voltage control TFT 53 means that the source-drain resistance of the voltage control TFT 53 is higher than the resistance layer resistance, so that the first electrode potential approaches the second electrode potential as the result of resistive voltage division.

Thereafter, in order to apply a writing voltage to the liquid layer in a subsequent writing period, the voltage of the drive power source line is changed to +Vdd but the voltage control TFT 53 is placed in the OFF-state. As a result, the first electrode potential is not changed.

In a subsequent field, a voltage Vt2 is written in the gate of the voltage control TFT 53, whereby the source-drain resistance of the voltage control TFT 53 is lowered. Here, by the resistive voltage division, the first electrode potential is controlled by the gate voltage of the voltage control TFT 53, so that a

voltage Vt2 for obtaining a desired gradation voltage Vw1 may be applied. Here, the reason why the voltage Vt2 is higher than the voltage Vt1 is that the voltage control TFT 53 is the n-type transistor which is a condition for writing the positive-polarity voltage of +Vdd and the source-drain resistance is high.

In a subsequent field, a voltage Vt0 is written in the gate of the voltage control TFT 53 to place the voltage control TFT 53 in an OFF-state, so that the first electrode potential approaches the second electrode potential as the result of the resistive voltage division.

Even such a driving method can suppress the resistance layer resistance in the neighborhood of the partition wall, so that the same effects as in the driving method described with reference to Figure 12. Further, by providing the voltage control TFT 53 as a means for controlling a current passing through the first electrode, a stable current is supplied to the first electrode even when the pixel TFT 46 is in the OFF-state. As a result, a potential drop can be prevented to effect good display.

Figure 14 is another equivalent circuit view at one pixel of the electrophoretic display panel 44, wherein in addition to the equivalent circuit shown in Figure 12, an AZ line 54, an AZB line 55, n-type transistors 56 and 57 (MN1 and MN2) and capacitors 58

and 59 (C1 and C2) are added.

Hereinbelow, a specific method will be described.

Figures 15(a) to 15(b) show drive waveforms at certain one pixel of the electrophoretic display panel 44. Here, the potential of the second electrode 7 is 0 V. Figure 15(a) shows a gate signal (scanning signal pulse) inputted from the gate driver 42, Figure 15(b) shows a signal line potential (data (information) signal pulse) inputted from the source driver to the pixel, Figure 15(c) shows an AZ signal and a resistance layer potential waveform, and Figure 15(d) shows an AZB signal.

In period 1, a level of the gate signal is raised, whereby the pixel TFT 46 is turned on. As a result, the drain electrode potential of the pixel TFT 46 is equal to the signal line potential Vdd. Thereafter, a level of the AZ signal is also raised to place MN1 in an ON-state. In a previous sequence, the AZB in the ON-state, so that the first electrode potential is substantially equal to the second electrode potential (0 V). Accordingly, gate-source voltage of the voltage control TFT 53 is negative, so that the OFF-state of the voltage control TFT 53 is ensured.

In period 2, a level of the AZ signal is raised, whereby MN1 is placed in an ON-state, and by the level of the AZB line, MN2 is placed in an OFF-state. As a

result, a current for Vdd flows into the gate of the voltage control TFT 53, so that electric charges flow until a gate-source voltage Vgs is equal to a threshold voltage Vth of the voltage control TFT 53. At the time of Vgs = Vth, the TFT 53 is placed in the OFF state.

Thereafter, when the level of the AZ signal is lowered so as to place MN1 in the OFF-state, the threshold voltage Vth is recorded (stored) in C1 and C2. More specifically, a voltage difference of C1 is Vdd-Vth and a voltage difference of C2 is also Vdd-Vth.

In period 3, when a signal having a level higher than Vdd by ΔV data is inputted in the signal line, the gate voltage of the voltage control TFT 53 is fluctuated by capacitive voltage division. In period 4, when the AZB signal is turned on, a current passes through the first electrode.

According to the above-described constitution, it is possible to compensate an irregularity in the threshold voltage Vth, so that even when the threshold of the TFT 53 varies pixel by pixel, a constant current can be passed through the first electrode. As a result, it is possible to prevent the fluctuation in first electrode potential caused by the irregularity in threshold of the voltage of the voltage control TFT 53, so that a desired gradation display can be effected. As a result, it is possible to effect

uniform and good display with no irregularity in an in-plane picture area of the electrophoretic display panel.

[Brief Description of the Drawings]

Figure 1 is a schematic sectional view showing a constitution of an electrophoretic display device according to First Embodiment of the present invention.

Figure 2 is a plan view showing a constitution of pixel in the electrophoretic display device in First Embodiment of the present invention.

Figures 3(a) and 3(b) are plan views each showing another constitution of pixels in the electrophoretic display device in First Embodiment of the present invention, respectively.

Figures 4(a), 4(b) and 4(c) are drive waveform diagrams of the electrophoretic display device in First Embodiment of the present invention.

Figure 5 is a sectional view for illustrating an equipotential line in a drive state of the electrophoretic display device in First Embodiment of the present invention.

Figure 6 is a schematic sectional view showing a constitution of an electrophoretic display device according to Second Embodiment of the present invention.

Figures 7(a), 7(b) and 7(c) are drive waveform diagrams of the electrophoretic display device in

Second Embodiment of the present invention.

Figure 8 is a schematic sectional view showing a constitution of an electrophoretic display device according to Third Embodiment of the present invention.

Figure 9 is a block diagram showing a system constitution of an electrophoretic display apparatus using the electrophoretic display device according to any one of First, Second and Third Embodiments of the present invention as a display panel.

Figure 10 is an equivalent circuit view at one pixel of an electrophoretic display panel of the electrophoretic display apparatus.

Figures 11(a) to 11(d) are drive waveform diagrams at one pixel of the electrophoretic display panel of the electrophoretic display apparatus.

Figure 12 is another equivalent circuit view at one pixel of an electrophoretic display panel of the electrophoretic display apparatus.

Figures 13(a) to 13(e) are drive waveform diagrams at one pixel of the electrophoretic display panel of the electrophoretic display apparatus.

Figure 14 is another equivalent circuit view at one pixel of an electrophoretic display panel of the electrophoretic display apparatus.

Figures 15(a) to 15(d) are drive waveform diagrams at one pixel of the electrophoretic display panel of the electrophoretic display apparatus.

Figures 16(a) and 16(b) are sectional views showing one pixel of a conventional electrophoretic display device.

Figure 17 is a sectional view showing an equipotential line in a drive state of the conventional electrophoretic display device.

Figure 18 is a sectional view showing one pixel of another conventional electrophoretic display device.

[Reference Numerals]

1: first substrate

2, 12: second substrate

3: dispersion liquid

4: charged particles

5: first electrode

6: partition wall

7: second electrode

8: display substrate-forming member

9: resistance layer

10a, 10b, 10c: coloring layer

11: contact hole

13: unevenness portion

14: connection material

41: panel controller

44: electrophoretic display panel

46: pixel TFT (thin film transistor)

53: voltage control TFT (thin film transistor)

[DOCUMENT NAME] DRAWINGS

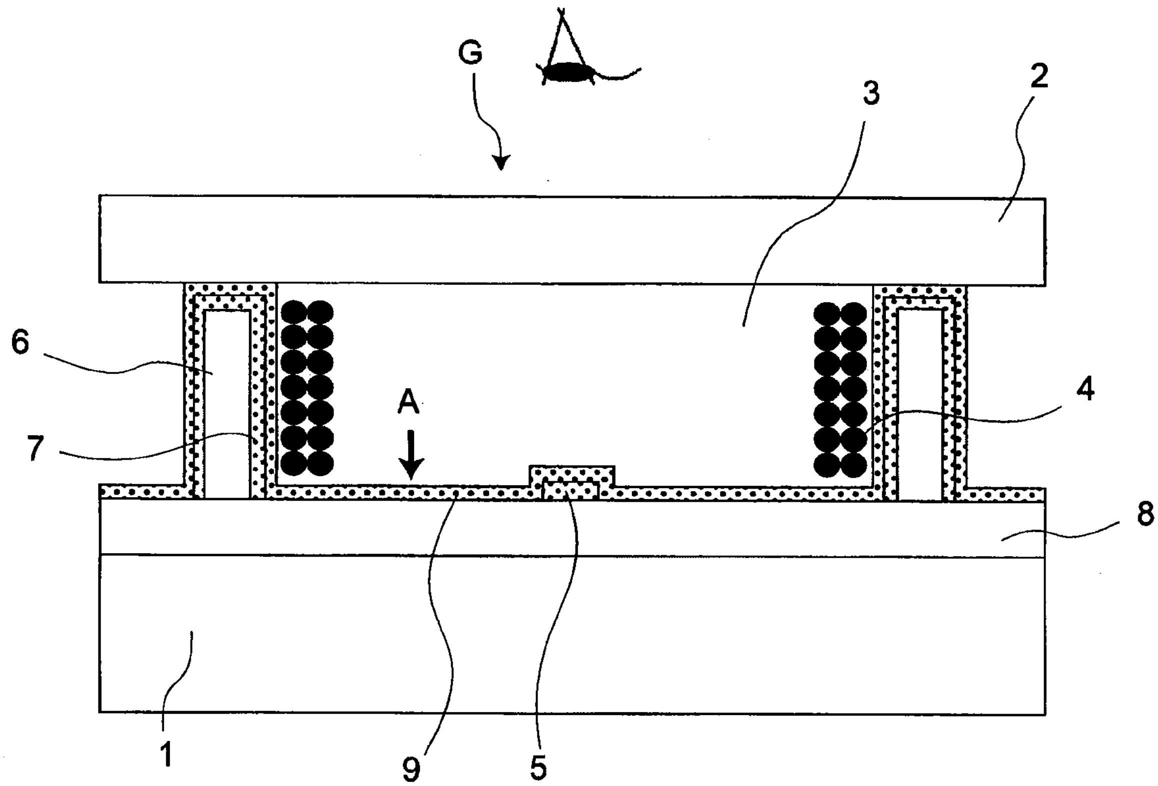


FIG.1

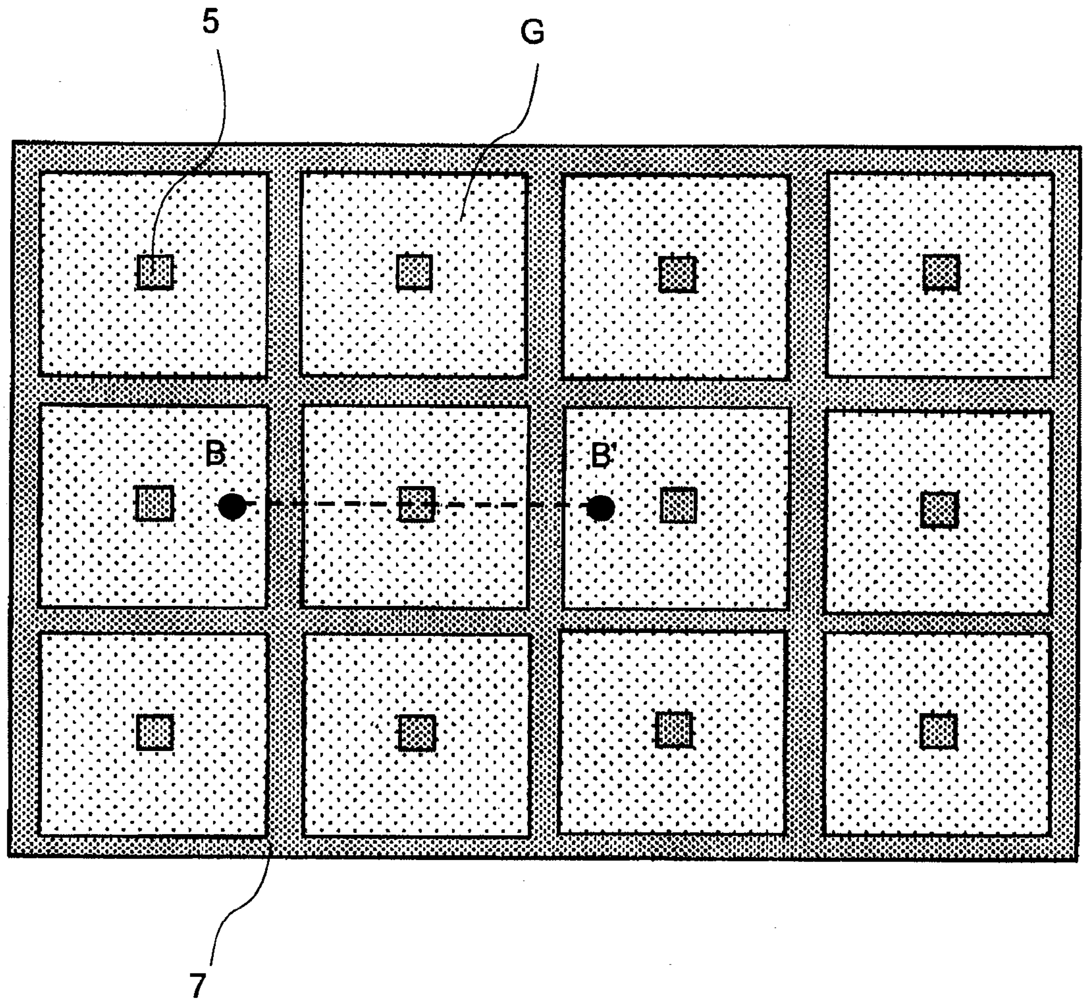


FIG.2

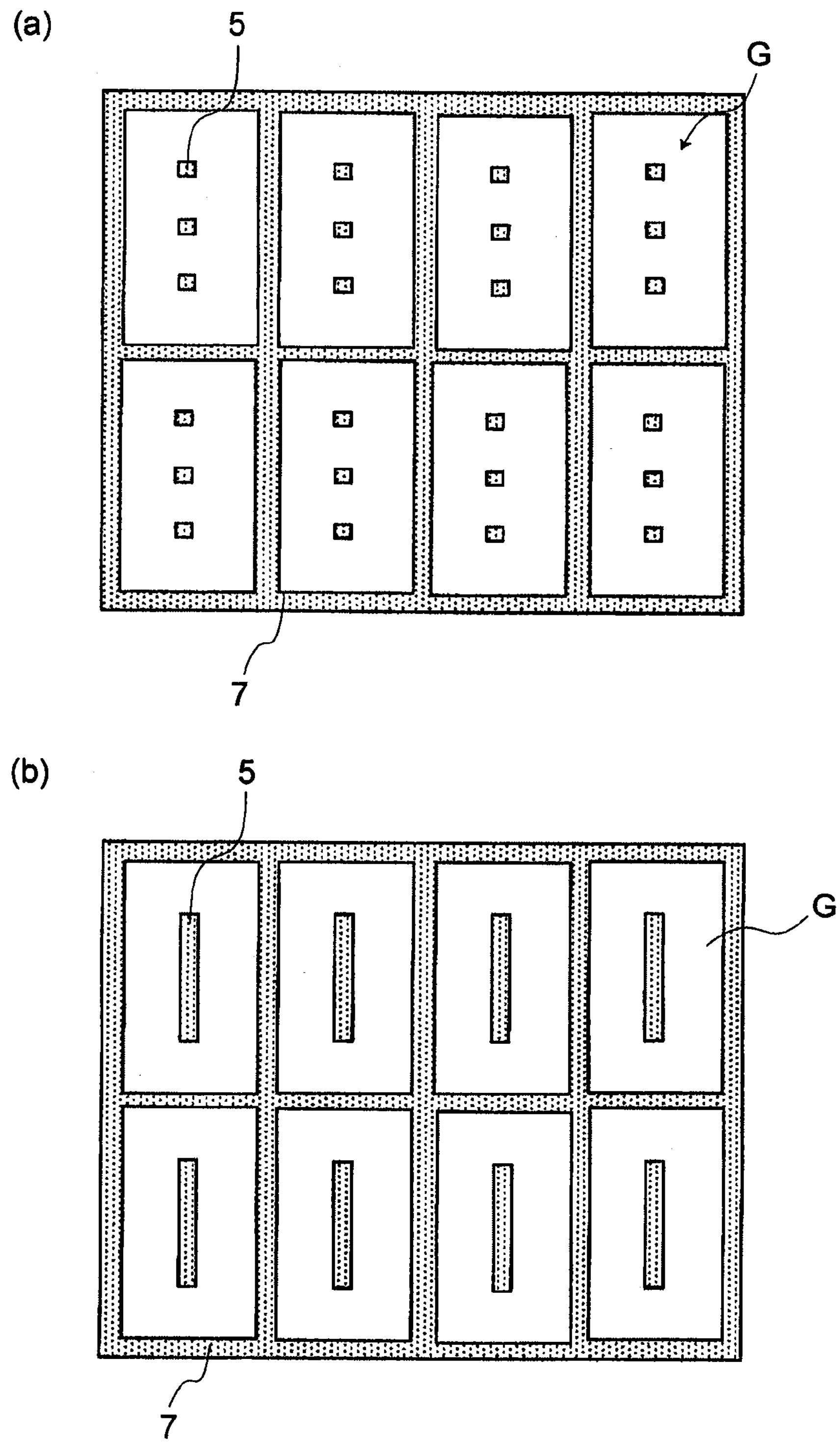
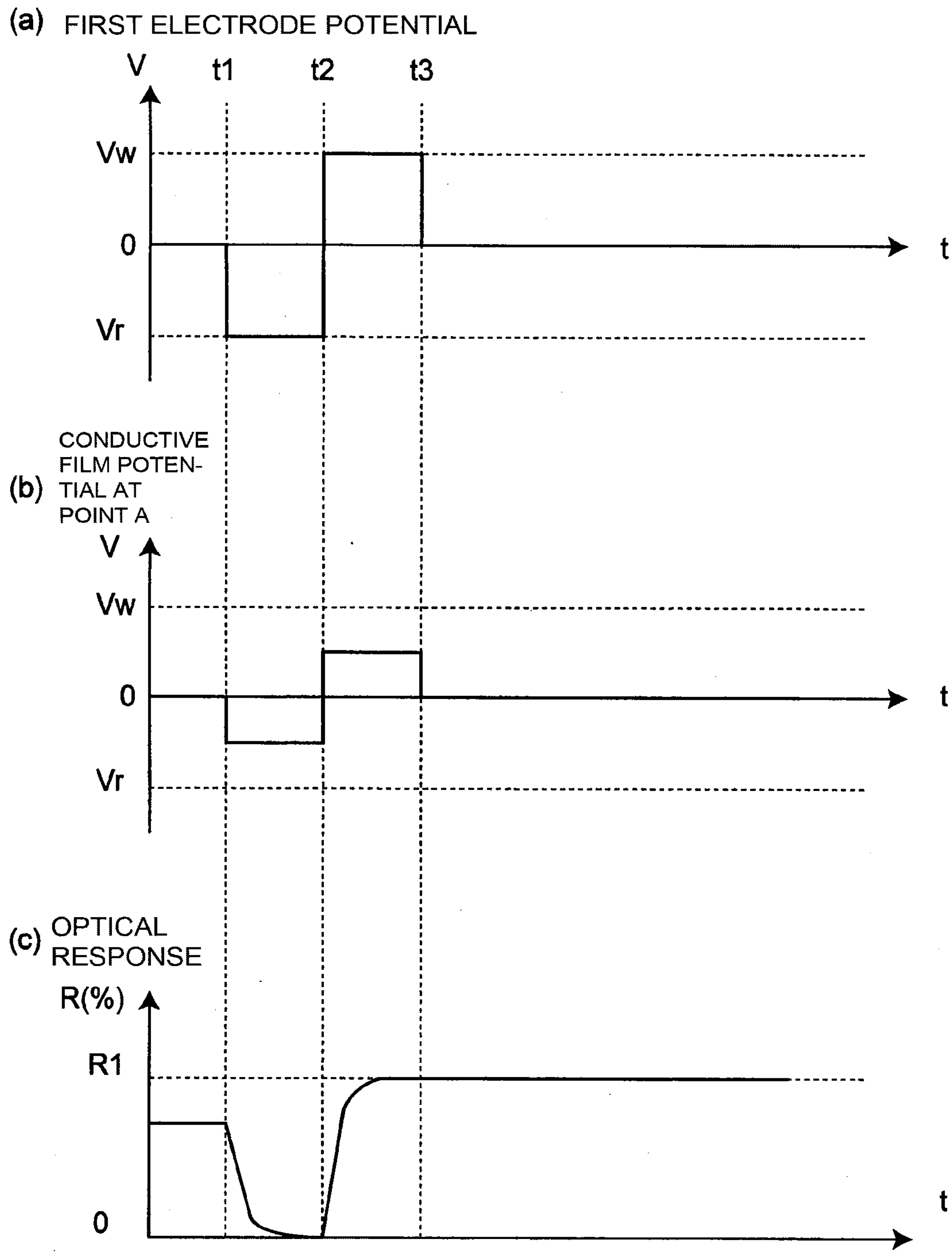


FIG.3



(a) FIRST ELECTRODE POTENTIAL
V
t1
t2
t3
Vw
0
Vr
t
(b) CONDUCTIVE FILM POTENTIAL AT POINT A
V
Vw
0
Vr
t
(c) OPTICAL RESPONSE
R(%)
R1
0
t

FIG.4

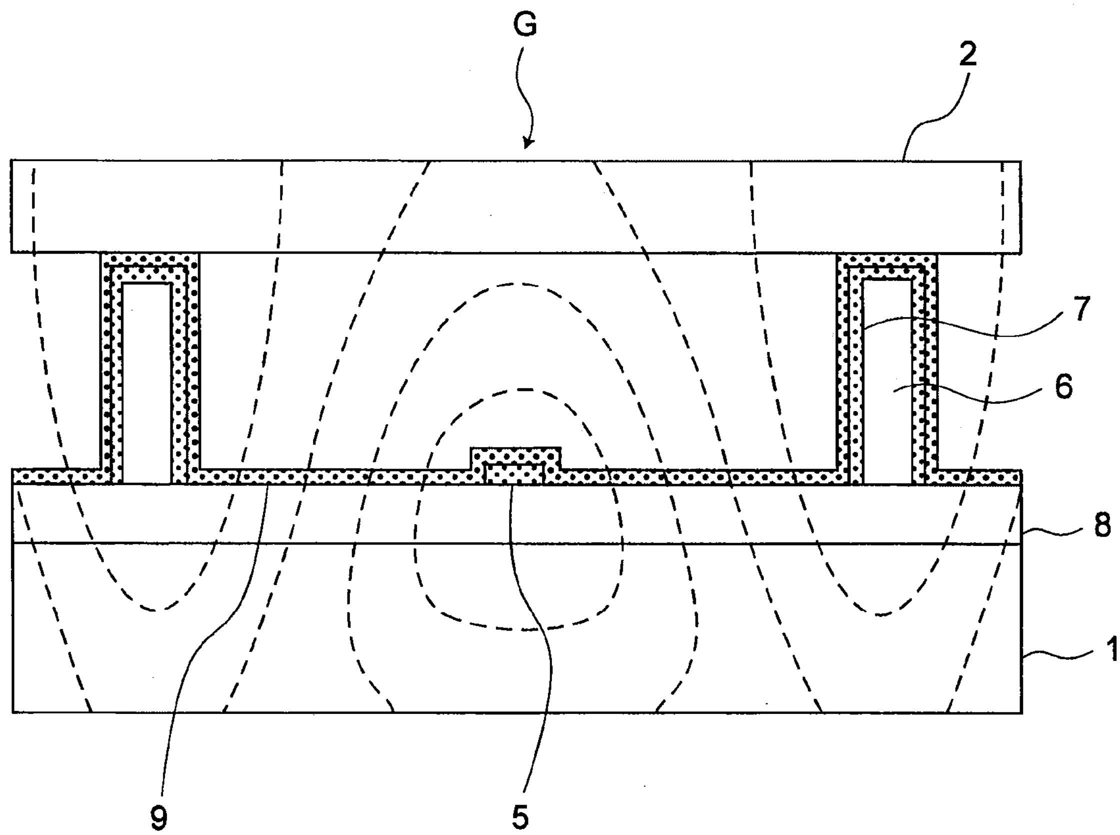


FIG.5

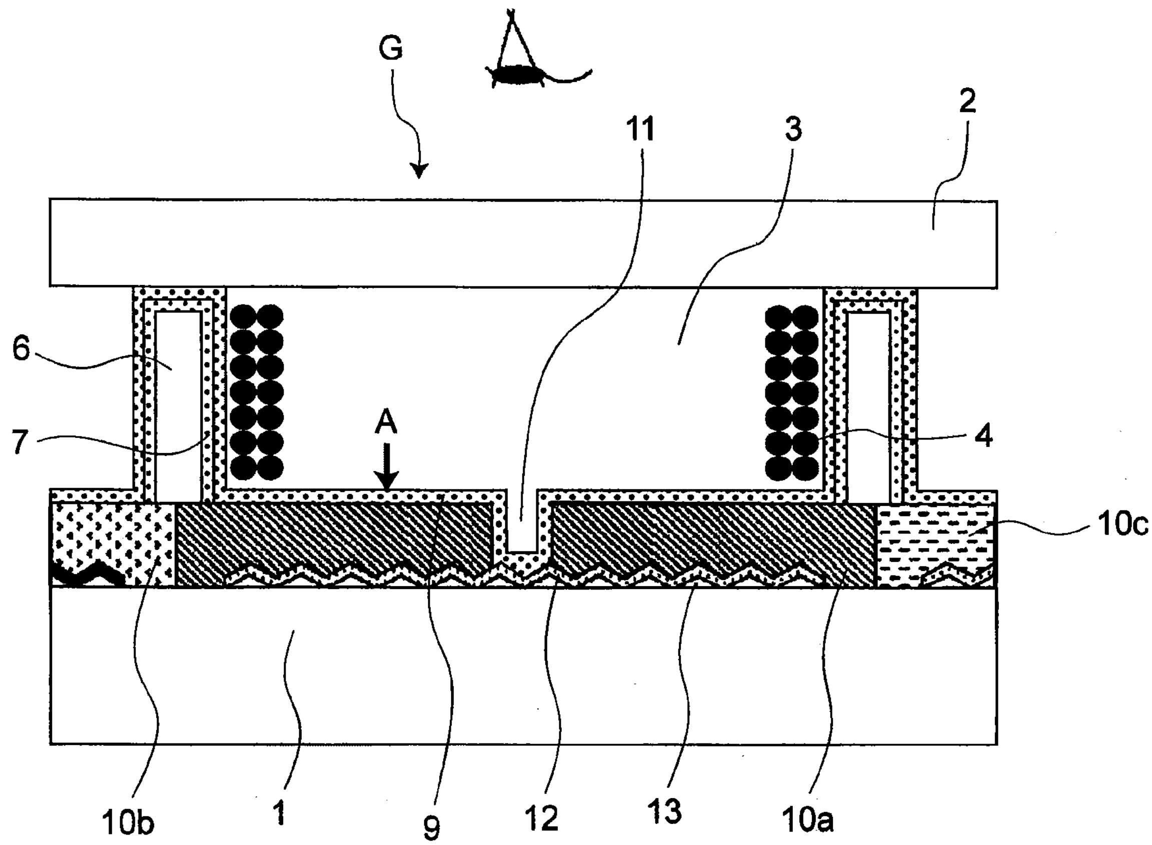


FIG.6

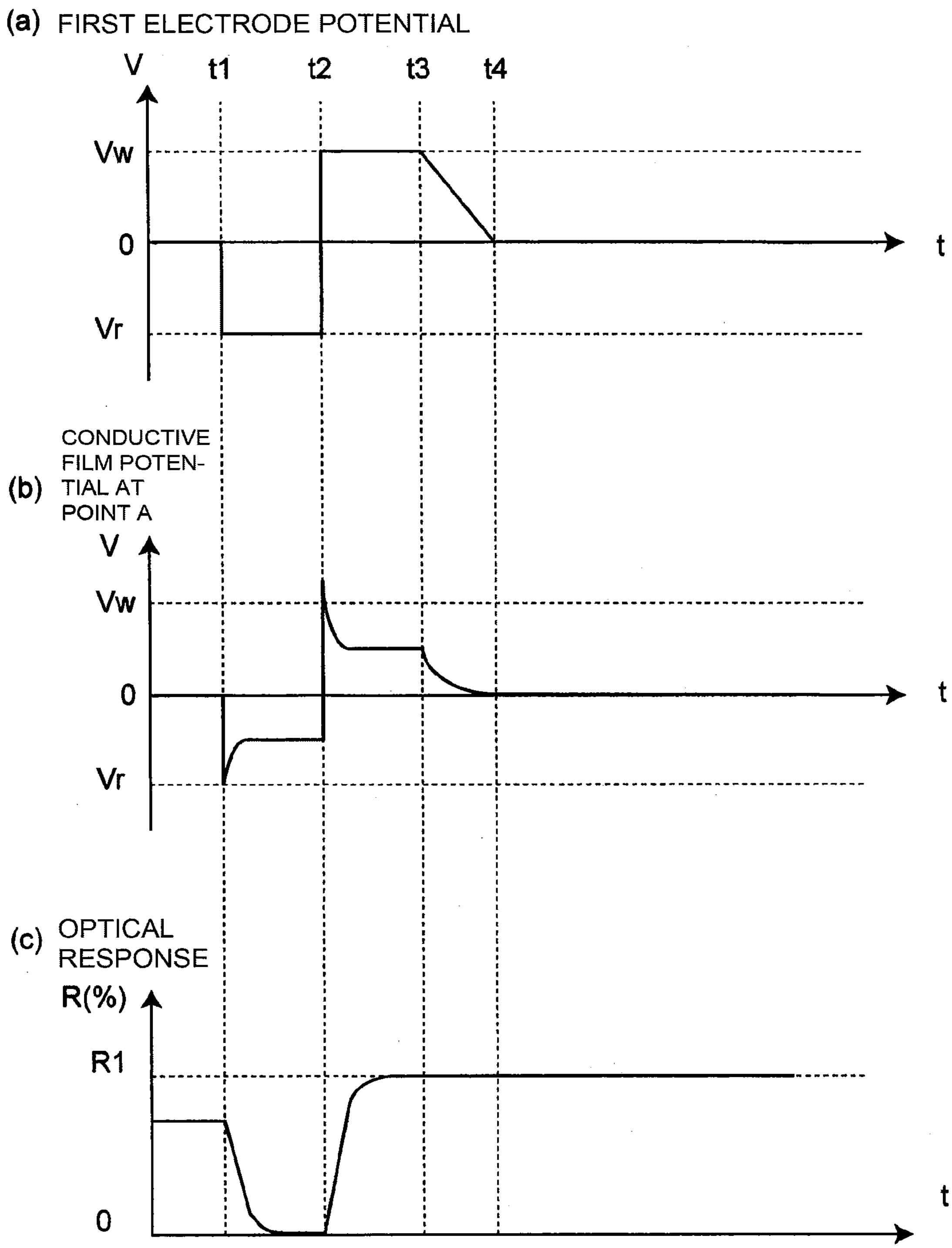

(a) FIRST ELECTRODE POTENTIAL
V
t1
t2
t3
t4
Vw
0
t
Vr
(b) CONDUCTIVE FILM POTENTIAL AT POINT A
V
Vw
0
t
Vr
(c) OPTICAL RESPONSE
R(%)
R1
t
0

FIG.7

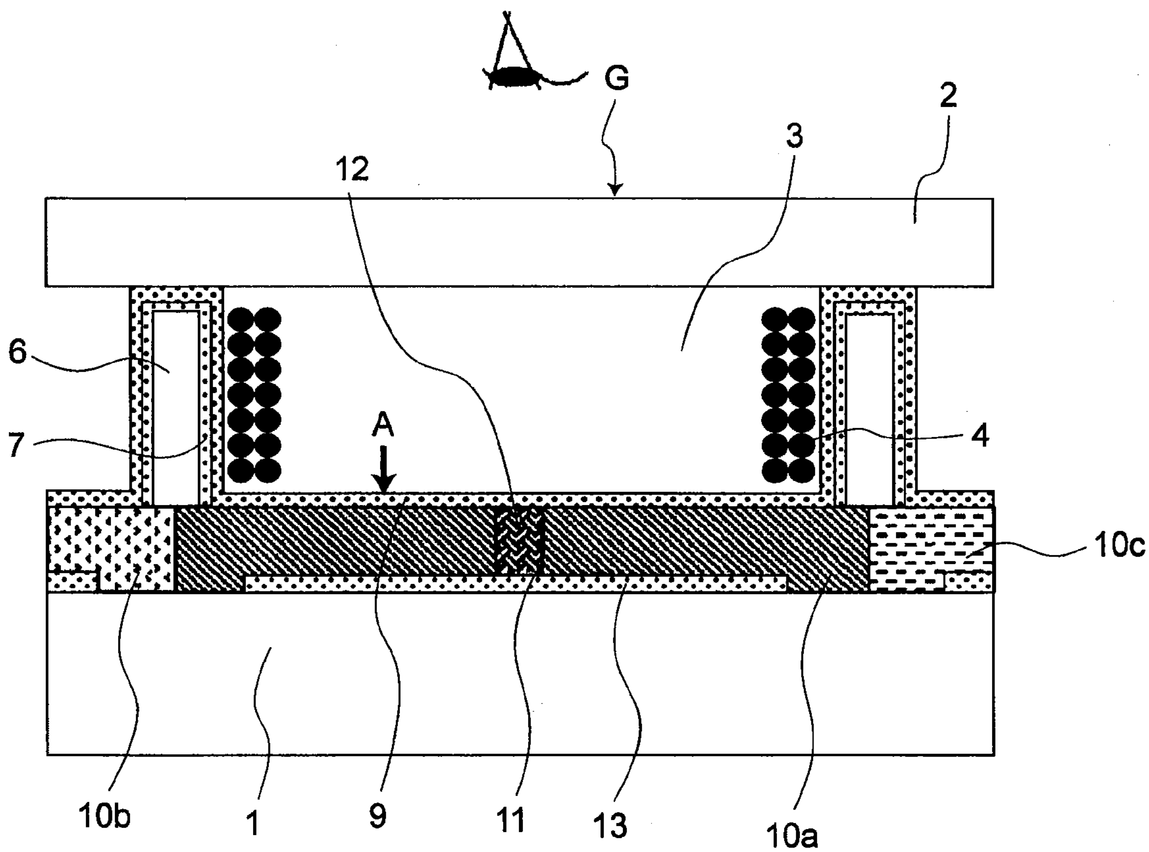


FIG.8

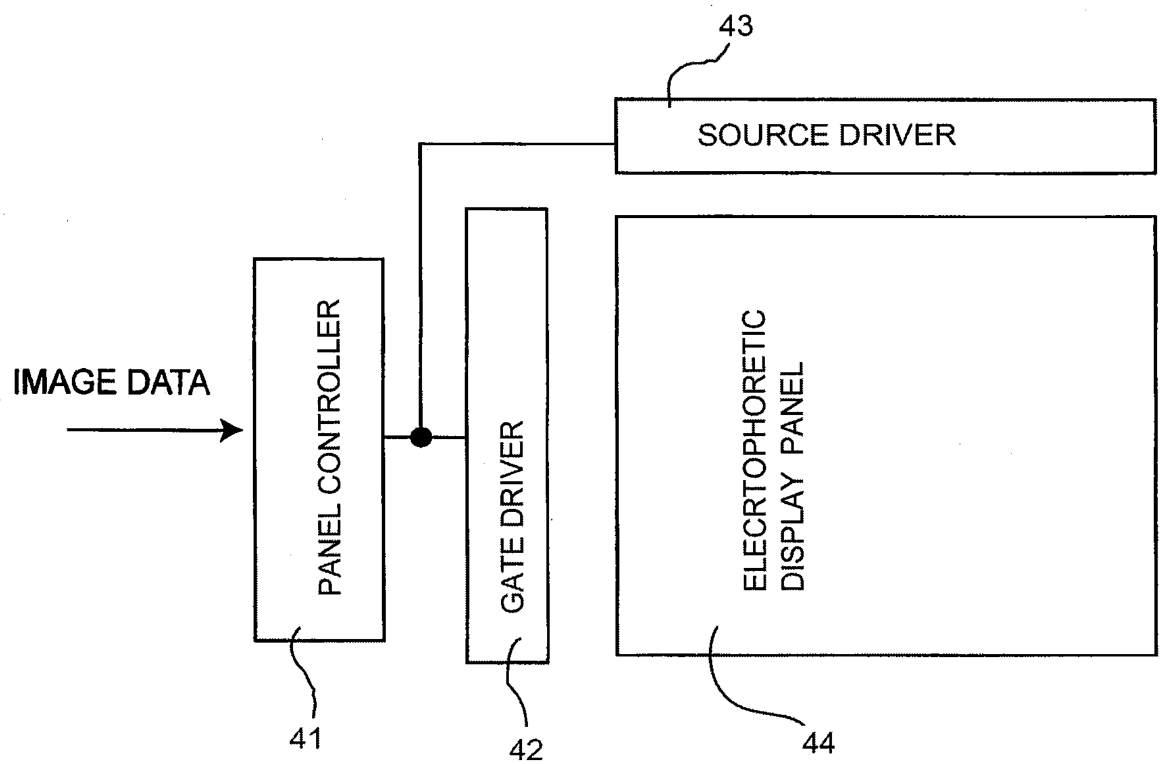

43
SOURCE DRIVER
IMAGE DATA
PANEL CONTROLLER
GATE DRIVER
ELECRTOPHORETIC
DISPLAY PANEL
41
42
44

FIG.9

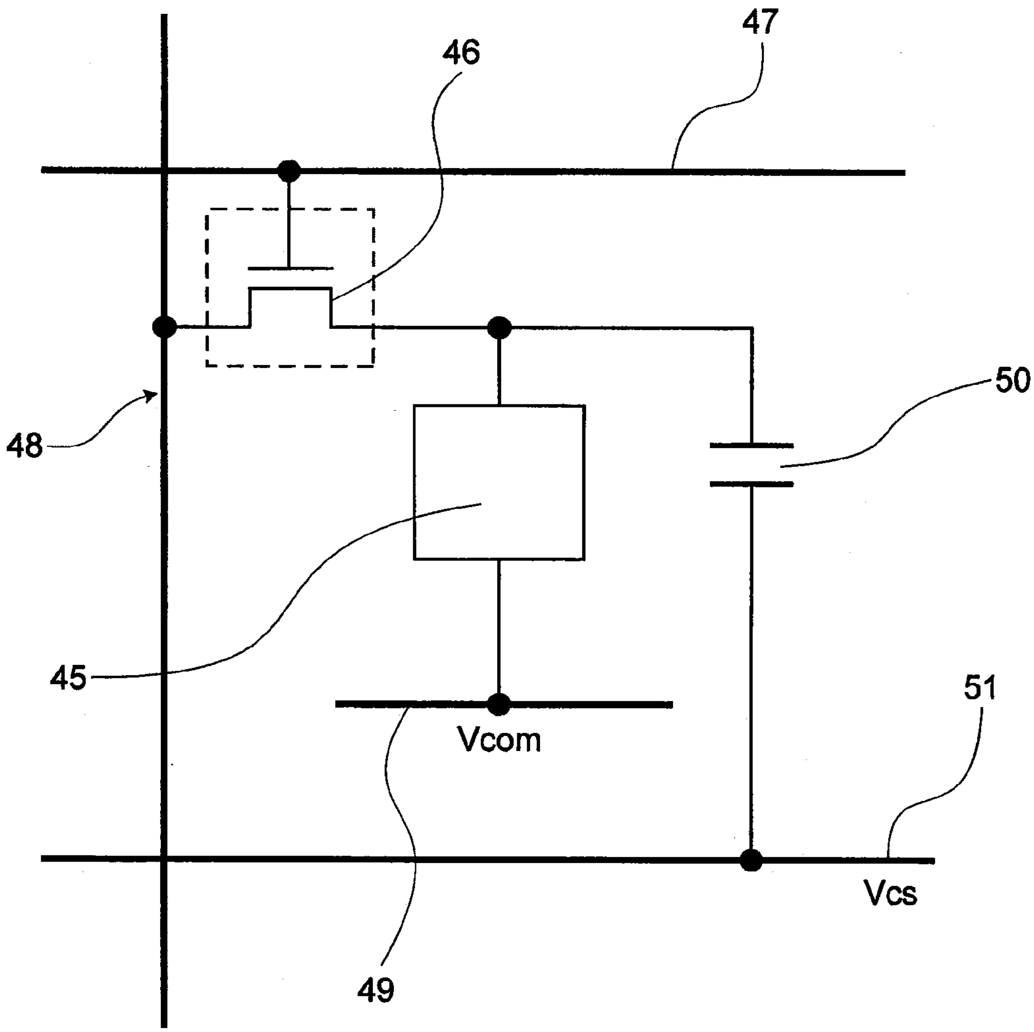


FIG.10

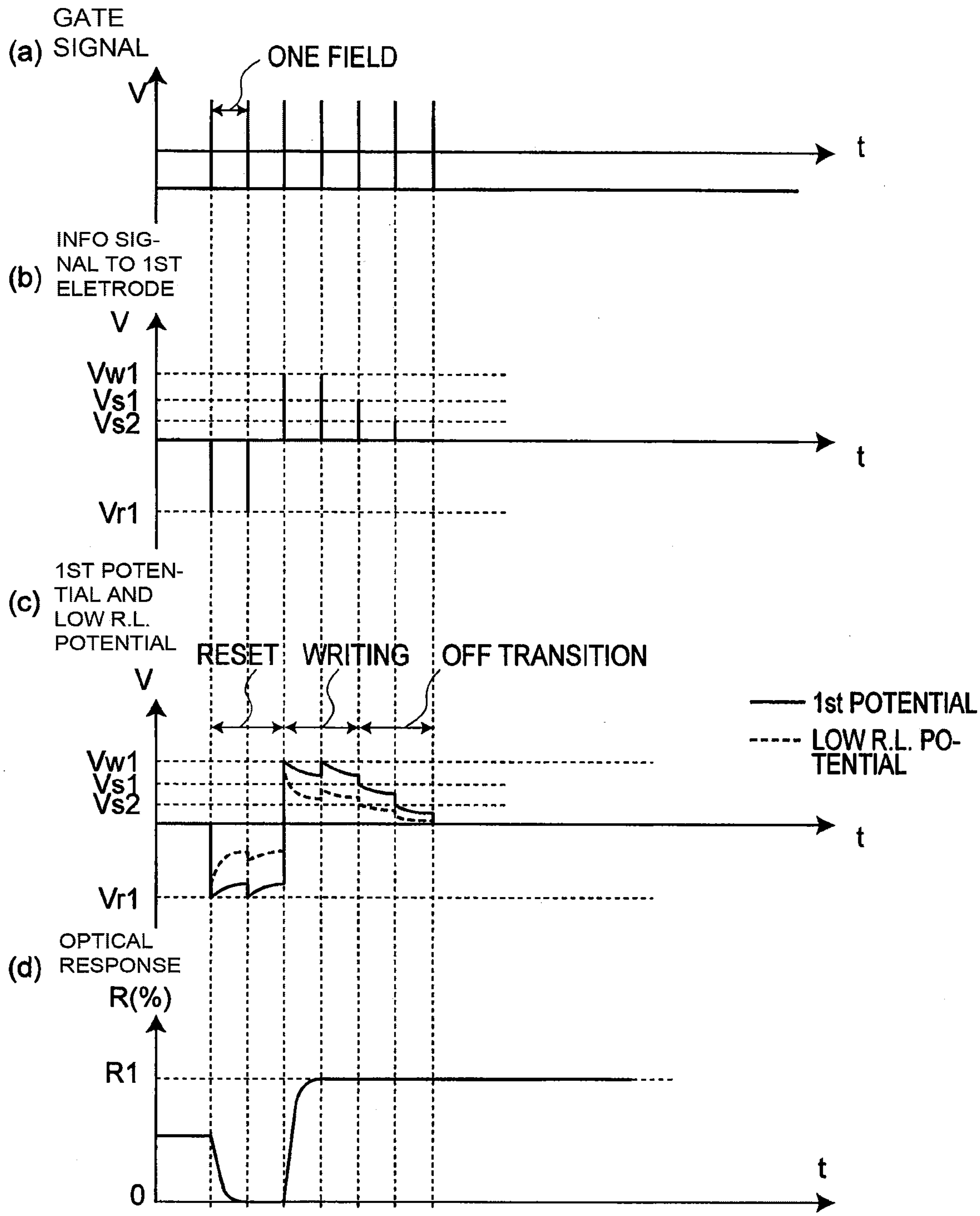

(a) GATE SIGNAL
ONE FIELD
V
t
(b) INFO SIGNAL TO 1ST ELETRODE
V
Vw1
Vs1
Vs2
Vr1
t
(c) 1ST POTENTIAL AND LOW R.L. POTENTIAL
RESET
WRITING
OFF TRANSITION
V
Vw1
Vs1
Vs2
Vr1
t
1st POTENTIAL
LOW R.L. POTENTIAL
(d) OPTICAL RESPONSE
R(%)
R1
0
t

FIG.11

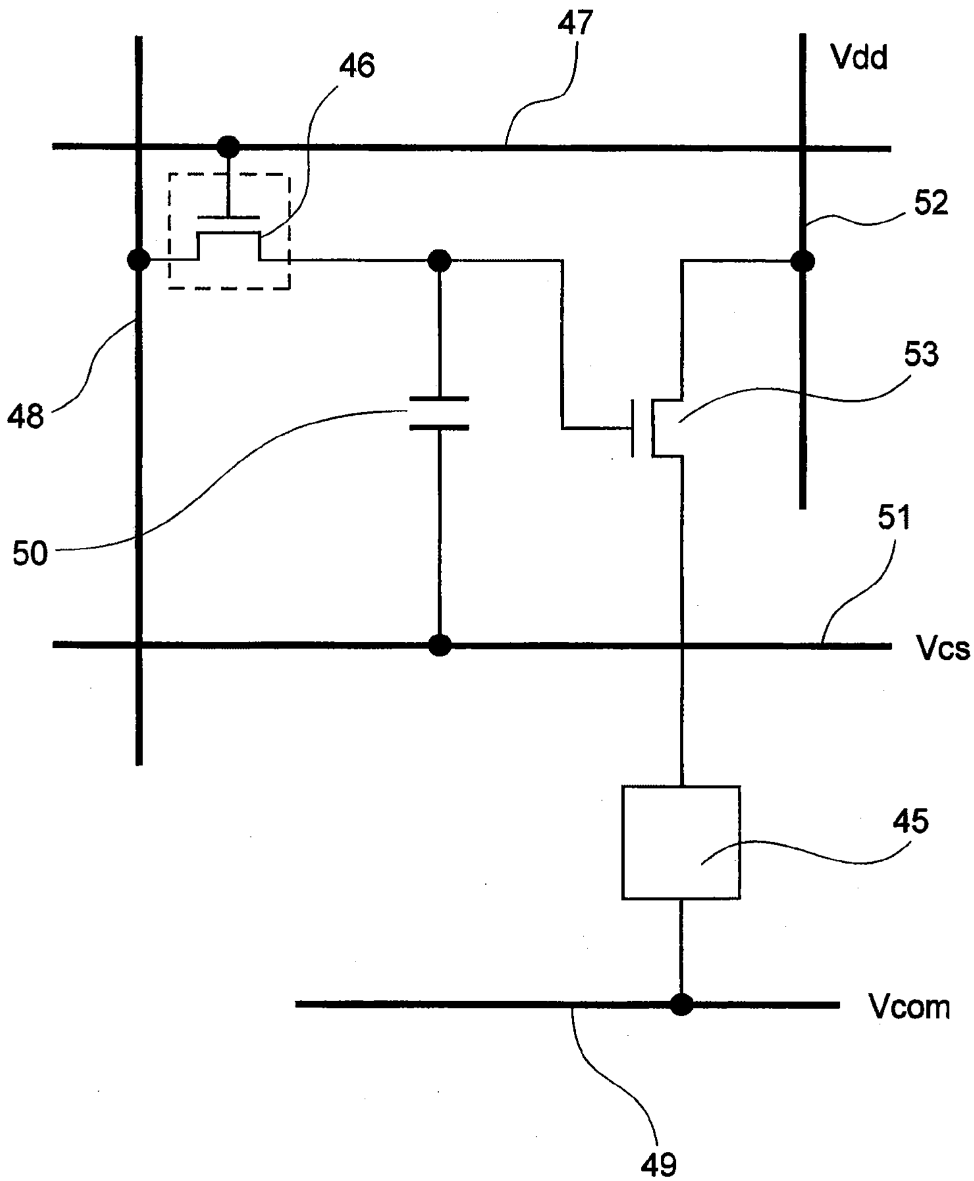


FIG.12

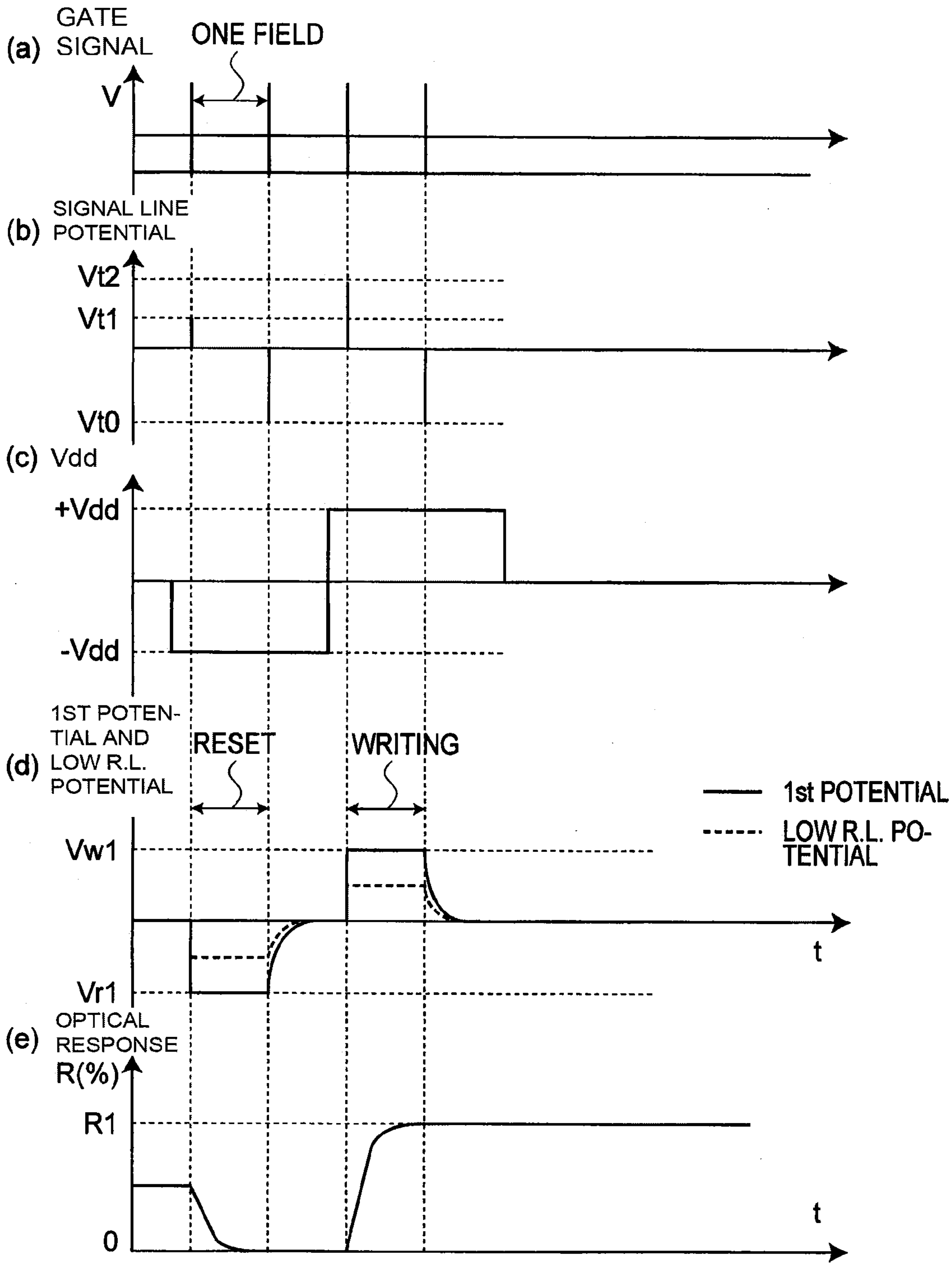

(a) GATE SIGNAL
ONE FIELD
V
(b) SIGNAL LINE POTENTIAL
Vt2
Vt1
Vt0
(c) Vdd
+Vdd
-Vdd
(d) 1ST POTENTIAL AND LOW R.L. POTENTIAL
RESET
WRITING
1st POTENTIAL
LOW R.L. POTENTIAL
Vw1
Vr1
t
(e) OPTICAL RESPONSE
R(%)
R1
0
t

FIG.13

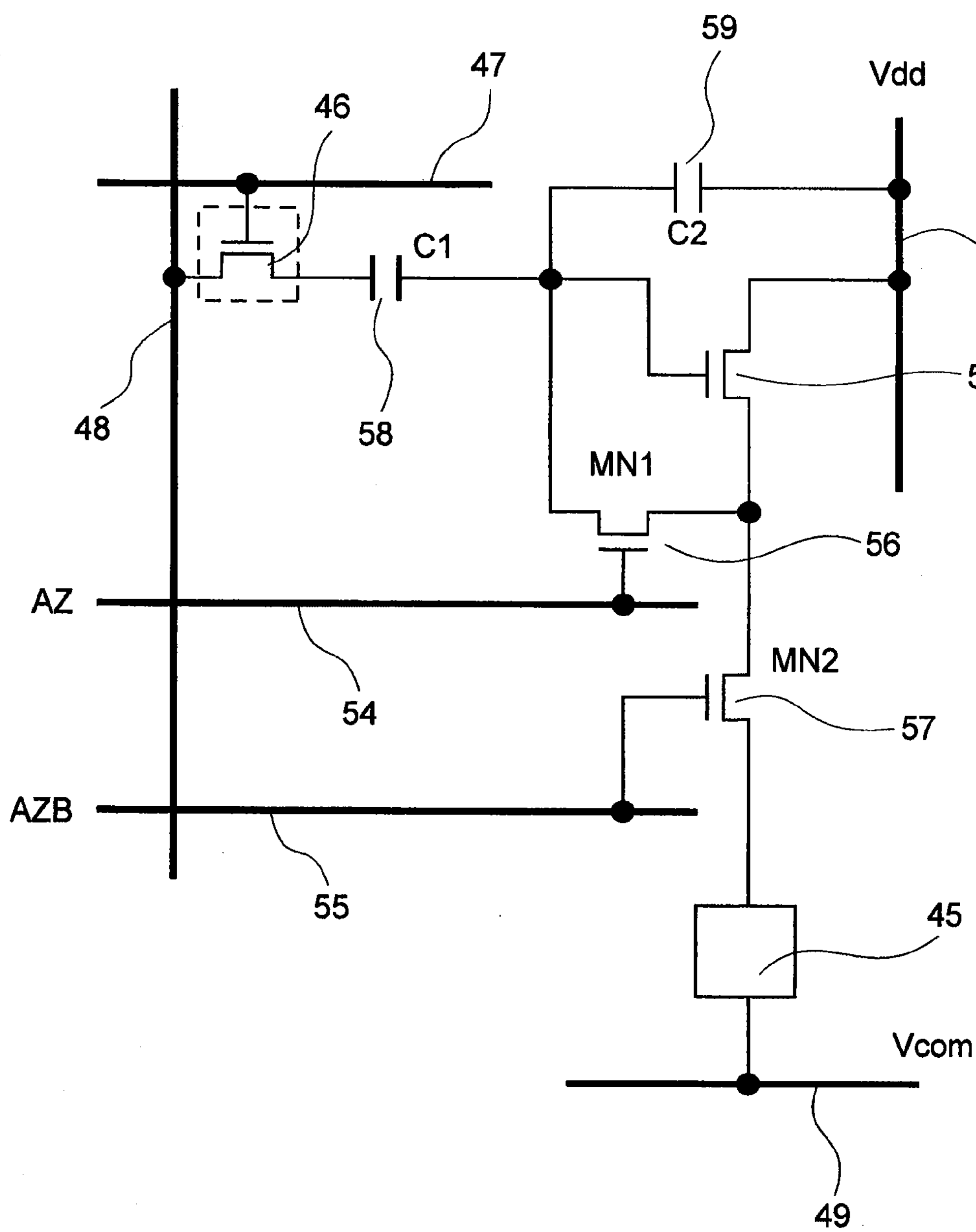


FIG.14

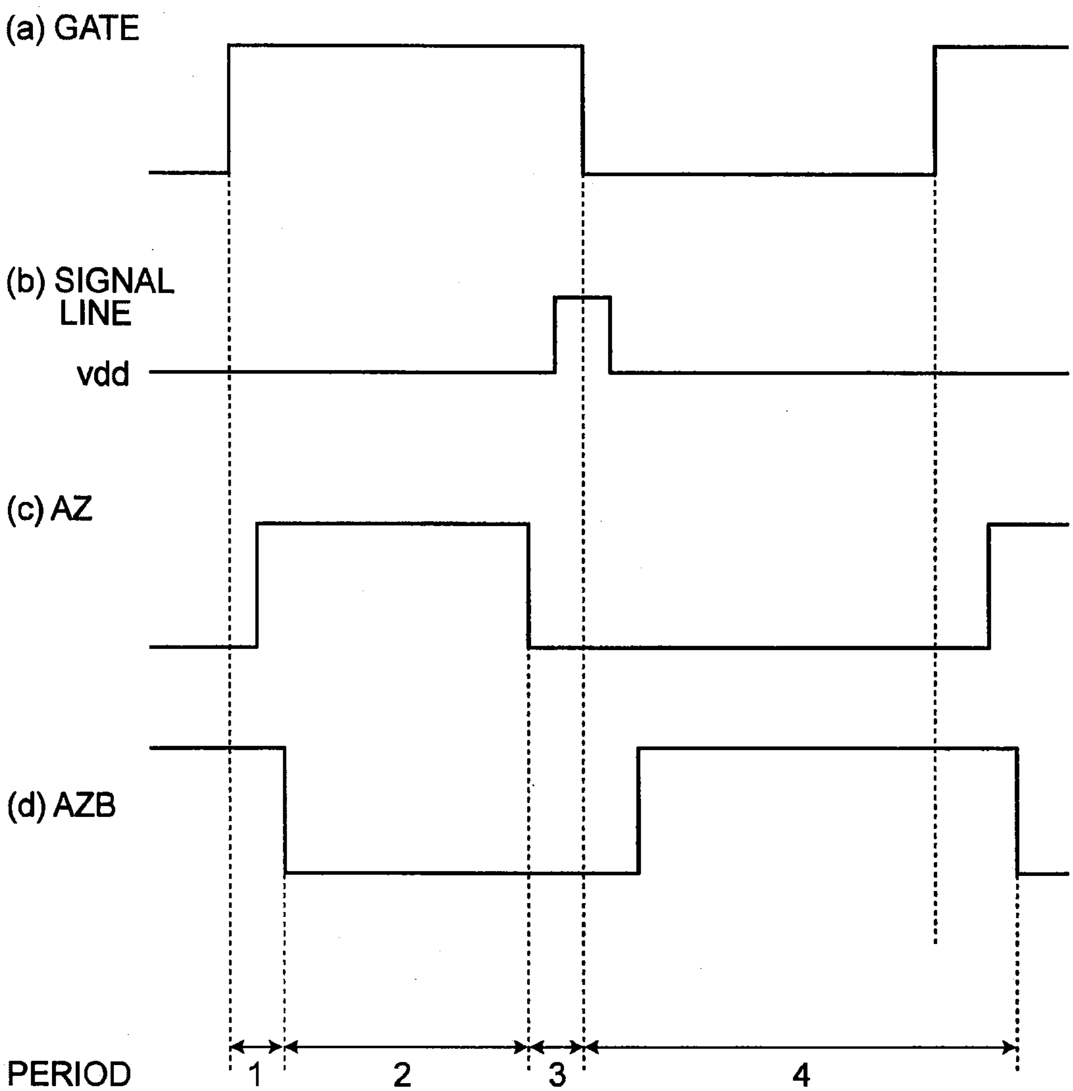
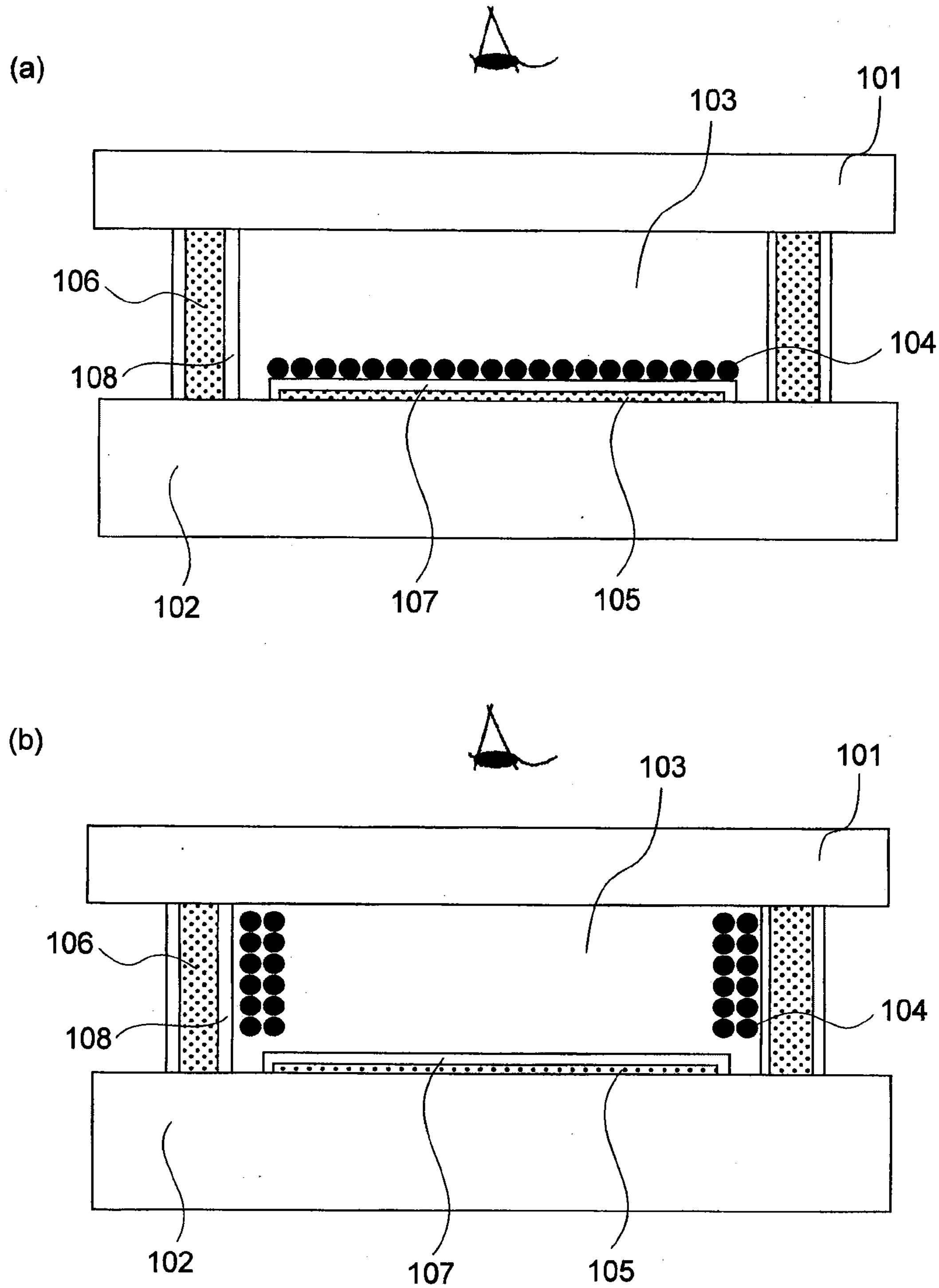


FIG.15



(a)
101
103
106
108
104
102
107
105
(b)
101
103
106
108
104
102
107
105

FIG.16

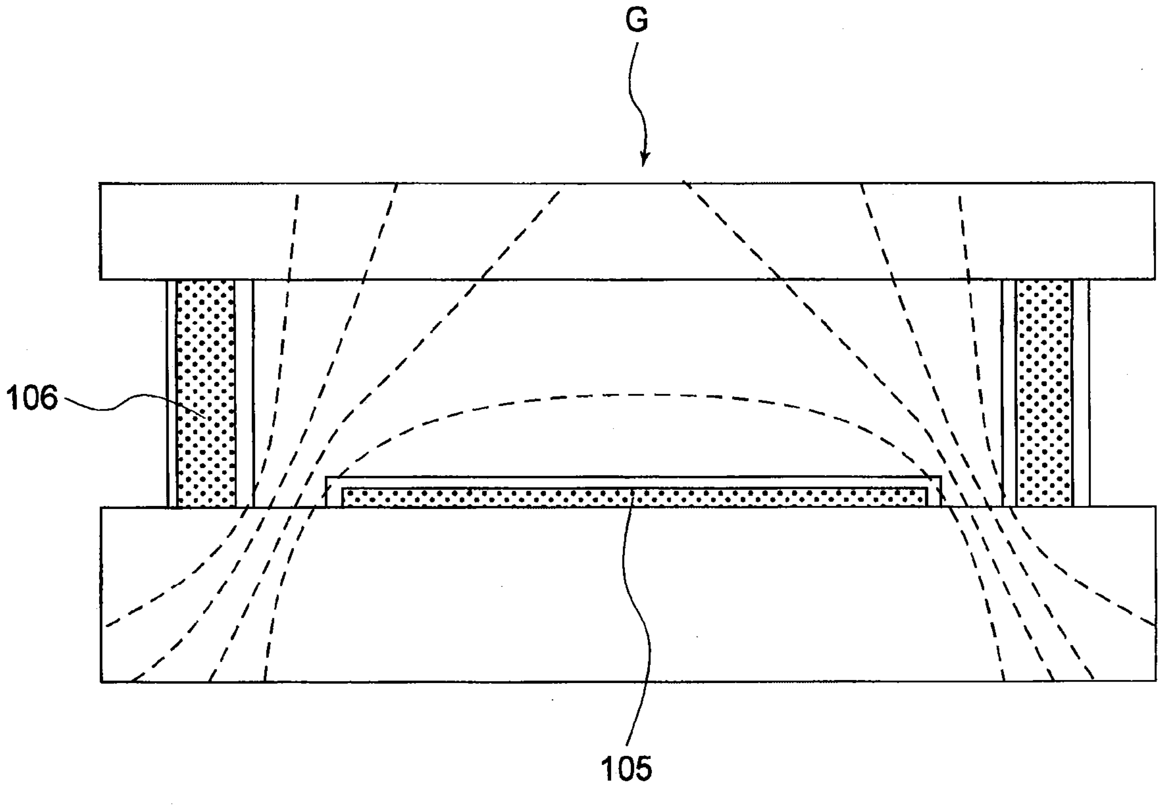


FIG.17

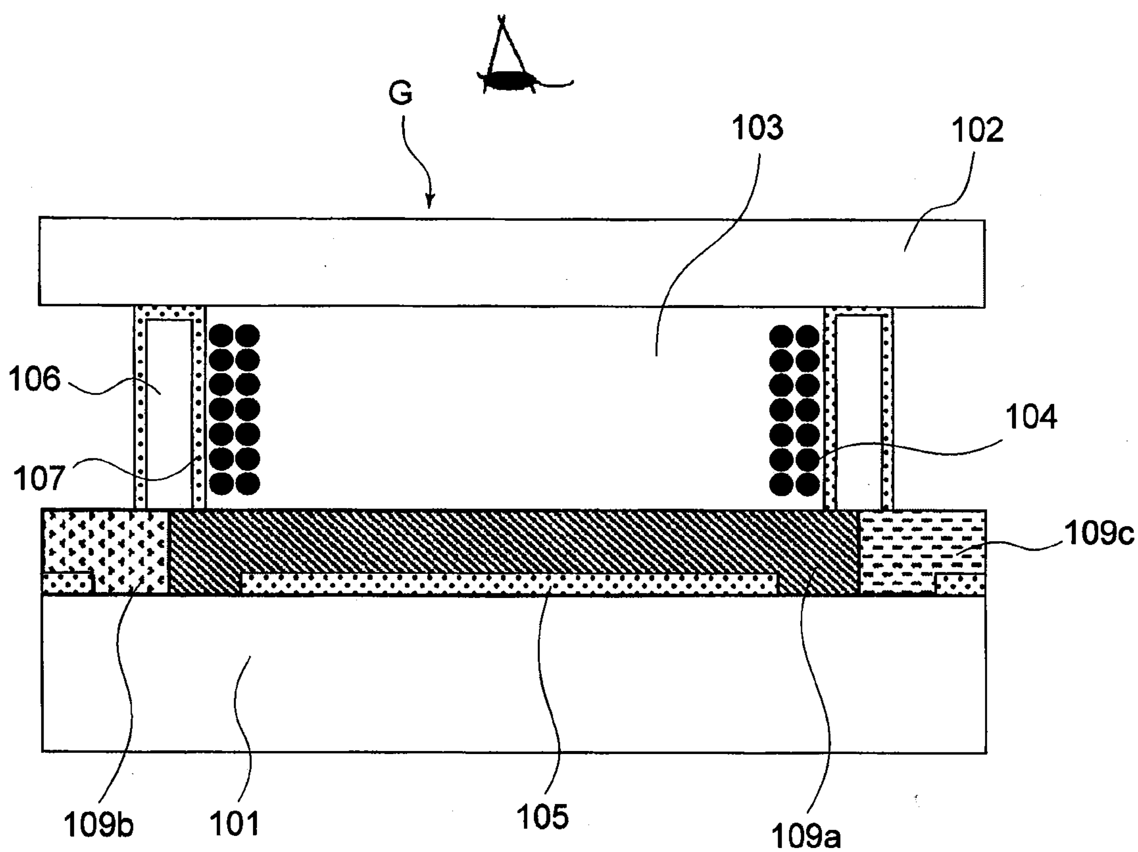


FIG.18

[Document]

Abstract

[Abstract]

[Object]

It is a principal object of the present invention to provide an electrophoretic display device capable of improving a contrast and remarkably retaining a memory characteristic, and a driving method of an electrophoretic display device.

[Means for Solving]

A first electrode 5 disposed on a first substrate 1 and a second electrode 7 disposed on a partition wall 6 are electrically connected with each other through a resistance layer 9, and an uniform potential gradient is generated in the resistance layer 9. As a result, it is possible to effect stable halftone display. Further, it is possible to remarkably improve a contrast, so that a sufficient memory characteristic can also be obtained.

[Selected Figure]

Figure 1